Challenges in the Development of Mobile P2P Applications and Services

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ABSTRACT

The recent trends of decentralizing enterprise applications toward the new peer-to-peer (P2P) architecture and the fast growth of wireless communication lead to a new tendency of combining these technologies to inherit their great advantages of mobility, reliability, flexibility and scalability. However, this technological integration raises a large number of new challenges and issues to be addressed. This paper focuses on the challenges of the development of enterprise mobile applications and services based on P2P architecture. Using selected results from related projects, we present and analyze these important issues and also propose an exemplary solution to address some of these issues.

I. INTRODUCTION

In the last decade, peer-to-peer (P2P) applications have boomed in the Internet and attract very much public interest. Prominent examples are eMule or BitTorrent file sharing [1] , Skype Voice-over-IP [12] Chord lookup directory [5] , or PPLive video streaming [9] . There are some major reasons for this success: [11] *a)* P2P offers new features not available by the underlying network and enables new services for end-users, e.g. application layer multicast or file sharing between groups of users; *b)* P2P systems are more economic than traditional systems like client/server thanks to the effective usage of shared computing resources and network bandwidth of all the systems that join the P2P network; *c)* the flexibility of P2P systems and operation on virtual overlay networks on top of existing infrastructures, like the Internet, allows easy development of new P2P applications; *d)* excellent scalability of P2P network thanks to its mechanism; *e)* P2P systems have very high reliability since most P2P designs successfully avoid single-point of failure; *f)* from developer's point of view, since most basic P2P development platforms already offer a large set of functionality to coordinate users and resources, comprising resource mediation and access control, replication management, node failure management, etc, they create a lot of opportunities and greatly accelerate the development of next generation collaboration applications.

As a result, P2P technology is an excellent candidate for enterprise mobile applications and services. However, since the enterprise environment requires the guarantee of certain service quality, very high reliability (e.g. 99.999%- or "*five nine*") and very strict security, basic P2P mechanisms need to be adapted accordingly. In addition, the wireless characteristics and features of the system have to be specially addressed.

Although P2P model has been long adopted for some enterprise applications, the development of enterprise mobile P2P services is still in a very early stage, which is reflected in a very limited number of studies in literature. In [7] Pakkala et al. proposed a *Conceptual Architecture of the Service Platform* based on the Generic Service Element (GSE) to facilitate the development of new enterprise mobile P2P services. Shan [15] proposed a hybrid P2P application architecture for improving the sharing of presence and other information between mobile clients and enterprise servers based on logical proximity. However, both papers only focus on the service platform and application level architecture without regard for some important characteristics of P2P mobile such as churn effects and energy limitation.

In the scope of this paper, we highlight challenges in networking aspects of mobile P2P applications and services base on our experiences in related projects. The rest of this paper is organized as follows. The next section provides some background information on P2P networks and two selected mechanisms, multi-source content download and distributed hash tables (DHT). The following section dedicated for analyzing major challenge of enterprise mobile P2P networks. These challenges are illustrated by some numerical results from our research projects, including the impact of churn on DHT and the impact of mobility on content delivery. Then a generic architecture of mobile P2P system is proposed in the fifth section to deal with common problems raised in the previous section. We show several solutions for the problematic issues of mobile P2P in the sixth section. Finally, we finish the paper by some concluding remarks and future work.

II. P2P NETWORKS AND MECHANISMS

P2P systems offer two fundamental mechanisms including resource mediation comprising functions for searching and locating resources, and resource access control for exchanging data. As a result, some P2P systems, such as BitTorrent [1] , may form two or more different logical overlays: e.g. search overlay and file distribution overlay.

The resource access control mechanisms determine the coordination and cooperation among peers, which actually permit, prioritize, and schedule the access operations to shared resources. Moreover, incentive mechanisms are applied to foster cooperation among peers and to stimulate users to voluntarily contribute their resources, e.g. the *tit-for-tat* strategy of BitTorrent, which determine the download bandwidth of a peer base on its offered upload bandwidth.

The classification of P2P networks is based on either the network topology (unstructured or structured) or the degree of centralization of the P2P architecture (pure or hybrid P2P).

An ***unstructured P2P*** arbitrarily establishes links between peers and forms a mesh. In general, file sharing applications rely on unstructured resource exchange overlay, as (parts of) files are directly exchanged among peers and the overlay links are established according to the applied cooperation strategies and incentive mechanisms. For resource lookup, some unstructured mechanism, such as Gnutella, uses flooding technique to broadcast query to neighbor nodes [11] . The unstructured P2P sometime are considered as 2nd generation P2P network.

In ***structured P2P networks***, which are also considered as 3rd generation P2P [11] , links are established according to a global rule, i.e. the position of all nodes and the links between peers is determined by a unique function, such as SHA (Secure Hash Algorithm) hash function. This function determines the neighborhood relationships among peers in the overlay. The most common core mechanism of structured P2P relies on Distributed Hash Tables (DHTs), e.g. Chord [5] , Kelips [3] , Tapestry [2] , Kademlia [8] , etc.

In contrast with unstructured network, the structured P2P greatly reduces unnecessary lookup traffic between peers since it firstly tries to setup a virtual topology of nodes with enough routing information and replication degree to deal with lookups and node failures. However, the change of topology due to frequent join and leave of mobile nodes might damage the stability of this topology and require costly topology update or even re-construction. Vice versa, unstructured networks do not have to pay the cost of topology maintenance and thus deal better with churn. This fact leads to the idea of a hybrid architecture of unstructured and structured overlay, which is adopted by the JXTA framework [5]

In ***pure P2P*** architecture all peers are assumed to be equal and play the same role, whereas in ***hybrid P2P*** systems peers are distinguished by their role and capability. The basic P2P functions can be implemented either in a centralized way on few well controllable entities, or in a decentralized way on a large number of self-controlled peers. Enterprise P2P applications are most likely rely on a hybrid P2P architecture which permits strict controllability to fulfill carrier-grade requirements. An example of hybrid P2P architecture is the eDonkey file sharing system, which contain both index servers storing file location and lower-level peers.

A. Distributed Hash Tables

As previously mentioned, Distributed Hash Table (DHT) is the core mechanism of structured P2P network. A hash table is essentially a data structure that associates keys with values. The DHT mechanism splits the key space and assigns ownership for participant nodes. Once nodes are connected in a virtual overlay, which has been established using a specific algorithm, they can find owner of any given key. In order to store a piece of data, such as a file in a DHT, an unique metadata, such as filename must be hashed to produce a key of fixed length and the current node have to invoke the function *put*(*k*,*data*) to nodes participated in the DHT, which actually forward a message through the overlay to the node responsible for the key *k,* which is also the node that store the pair *(k, data).* The lookup process for the content of a file can be performed by simply reproducing the key *k* by hashing its filename and then querying the overlay for the associated data by invoking the *get(k)* function. This actually routes the query through the overlay to the responsible node for *k,* so that it can reply with the stored data. Each node must stores contact information about other peers for successful routing query messages. Some replication mechanisms are also available to deal with node failures and topology change.

B. Multi-Source Download for Content Distribution

An efficient and robust way of cooperative content delivery is the multi-source download (MSD), also denoted as swarming, which allows recipient peers to request and download desired data from multiple providing peers instead of a single one. The efficiency of MSD was demonstrated by the success of eDonkey and BitTorrent.

MSD is enabled by splitting files into chunks and blocks (subparts of chunks). In the case of eDonkey, the typical size of chunk and block is 9.5 MB and 180 kB, respectively. A downloading peer requests blocks from serving peers, i.e. sources of that file, and may download from these sources in parallel. As soon as a peer has downloaded a complete chunk, it becomes a source for the file, so that it can redistribute the already received chunks. MSD benefits P2P networks by speeding-up data download and quickly creating additional chunk sources. Therefore, MSD can avoid bottlenecks and overcome churn effects.

While the number of parallel download connections of a peer is typically not limited, the number of parallel upload connections is restricted to a maximum of *n* to guarantee a certain minimal bandwidth. Bandwidth of a peer is shared between upload and download traffic and if a downloading peer cannot handle the upload bandwidth due to its limited download bandwidth, the surplus is equally divided among other peer connections. This phenomenon shows strong effect in heterogeneous mobile environments due to frequent capacity changes caused by mobility and vertical handovers between access technologies.

When a provider peer already serves *n* peers, it pushes the request into its uplink waiting queue. As soon as an upload connection becomes available, the first peer in the queue is served. However, this queue can be prioritized based on the contribution of the requesting peer to the network. In heterogeneous wireless environments, this policy becomes inefficient since a WLAN user might easily serve a large amount of GPRS users regarding their large bandwidth difference.

III. CHALLENGES OF ENTERPRISE MOBILE P2P

The challenges of enterprise mobile P2P inherit from the current problematic issues of mobile computing, P2P network and a very large number of new problems caused by the integration of these technologies, which is also the focus of this paper.

Current enterprise applications are established mainly in wireline local area networks (LANs), which is the ideal environment with high bandwidth, low latency, high reliability and security. However, multi-national corporations have to build large virtual networks by interconnecting their LANs from different geographical locations by using Virtual Private Network (VPN). Common problems arise as cost-effectiveness, security, QoS guarantee, and scalability for such a large number of users on heterogeneous networks in various locations.

Nowadays, enterprises often require mobility and flexibility of their workers in field applications, and team collaboration. For example, workers should be able to use enterprise applications and to collaborate with other workers anywhere, anytime in an economic and secure way. Major collaboration features include: *a)* the direct exchange of data and information like user presence or resource information, *b)* distributed storage or version control systems for documents & source code, and *c)* conferencing systems with integrated features like whiteboards or presentations.

A large number of wireless access technologies such as WiFi, WiMax, GSM, CDMA, etc. are very different in bandwidth, coverage and reliability but share some common problems of intermittent connectivity, asymmetric downlink/uplink bandwidth, lack of QoS support, high latencies, security, limited and high cost bandwidths, IP address change due to mobility, and end-user terminal diversities. Next, we highlight some problematic issues of P2P mobile network.

A. Wireless & Mobility

The mobility may invoke abrupt bandwidth changes, e.g. due to vertical handover between different access technologies or due to the nature of the wireless channel, like HSPA (High Speed Packet Access) in UMTS (Universal Mobile Telecommunications System). This increases the peer heterogeneity and requires a dynamical adjustment of the overlay topology and resource management. Another consequence of mobility is the loss of IP addresses of mobile node causing a user to appear as a new peer in the P2P system and eliminate all his previously earned credits for sharing resources.

B. Churn Problems

While in wireline P2P, the join and leave of a node (named as churn) is mostly under user control and occur in rather low frequency (every 1-2 hours), in wireless P2P, the causes of churn are most likely out-of-control and its frequency is much higher (every 30 to 600 sec). Some possible reasons are: a) intermittent radio link, *b)* the battery saver mechanism of mobile terminal, *c)* user turns off or puts his mobile terminal in standby mode.

The churn decreases the overall performance of entire P2P system, as can be seen in the next section.

C. Peer Heterogeneity

The heterogeneity of peers has to be taken into account to efficiently coordinate and manage peers and resources.

From developer view point, due to the large difference between manufacturers, operating systems, capability, and versions of mobile terminal, it is very difficult to develop software to run on a large range of mobile devices. One solution is to deploy only medium or thin client software at mobile terminal and push the rest of computing burden to more powerful network entities. In term of networking resource, for example, a WLAN mobile user may have bandwidth several times higher than that of a GPRS user.

D. Energy

In contrast to traditional Client-Server (C/S) systems, where most traffic first start intentionally from client base on its needs, peers in P2P network produce much more frequent unintentional traffic, which can quickly deplete battery of mobile terminals. In term of energy-saving, structured P2P seems more favorable than unstructured P2P when the topology is in stable status, but under high churn rate unstructured P2P has advantage of paying no cost for updating the topology. Again, these issues are still open for further researches.

E. Peer behaviors & Security

The behavior of a peer strongly impacts the performance of a P2P system. For example, a user may behave selfishly and try to minimize the data upload. In the context of mobile networks, selfish behavior appears even more distinctive (e.g. in order to save battery resources and expensive uplink capacities).

Even worse, fake or corrupted contents offered by the malicious peers may disturb the entire data dissemination process. This is known as *system poisoning* and *pollution* that waste a huge amount of bandwidth and even make some users give up file sharing session.

In contrast with passive client in C/S model, software running at peer plays a very active role in the P2P system, which even harms the whole system. As a result, more security problems arise such as various types of attacks, exploits, virus spread, and the reverse engineering of binary code to create malicious node. Moreover, the open nature of wireless environment greatly increases the number of security threats, such as attacks on data-link and physical layers (e.g. radio jamming).

Several authentication mechanisms were considered for distributed environments such as Kerberos and SPX [13] , which are all ticket-based. However, the efficiency of the combination of these techniques with current wireless security mechanisms regarding energy and performance is still an open question.

F. Other Issues

The quality aspects of enterprise class network include reliability; service availability and robustness require modifications of basic P2P mechanism to improve certain performance metrics, e.g. lookup latency.

IV. SELECTED EXAMPLES FOR TYPICAL PROBLEMS IN MOBILE P2P SYSTEMS

In this section, we illustrate typical problems of mobile P2P systems in two selected examples. First, the impact of churn on the performance of DHT-based lookup systems is emphasized. After that, the impact of mobility on the performance of content distribution networks is shown.

A. Impact of Churn on DHTs

As previously mentioned, churn rate of mobile nodes are much higher than that of fixed nodes in wired networks, which require significant modifications in P2P mechanisms.

Since DHT algorithms try to establish and maintain certain overlay topology (such as the ring topology in Chord), high churn rate will greatly affect topology stability, causing sharp increase in both communications cost to re-establish partnership between neighboring nodes and time of successful lookup.

In order to study the impact of churn on DHT performance, we characterized three popular DHTs including Chord, Kelips, Tapestry using P2PSim, a discrete event simulator. We run more than 12.000 simulations on P2PSim to simulate networks of various sizes ranging from 100 nodes to 1000 nodes implementing these DHTs under high and very high churn rate from 100 to 600 seconds (i.e. the mean interval between node join and leave).

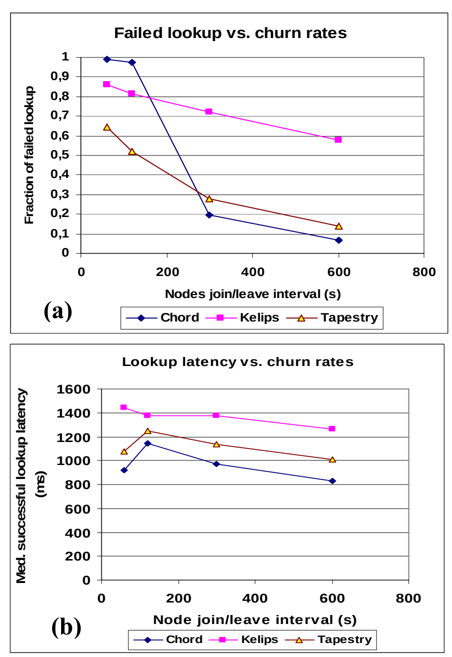

Figure 1: The effect of churn rate to fraction of failed lookups (a) and the medium of successful lookup latency (b) in network of various sizes

Figure 1 presents the effect of churn rate to fraction of failed lookups (a) and the medium of successful lookup latency (b) in the network of 1000 nodes. From this figure, one can observe the tolerance of each DHT under churn. For example, Chord perform the best among three DHTs under churn rate from 300 to 600 sec, but it quickly fails and become the worse when churn rate increases beyond 300 sec. Unmodified Tapestry DHT can be considered as the best DHT among three under high churn as its performance gracefully degrades and is still acceptable when churn rate exceed 300 sec.

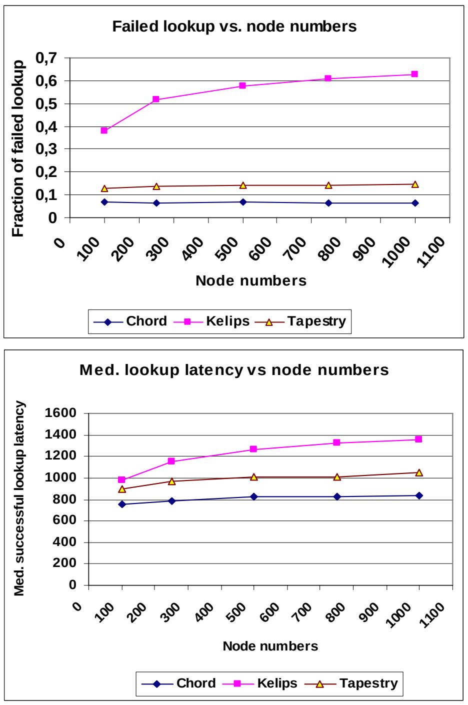

Figure 2: The scalabilities of DHTs

The good scalability of DHTs can be observed is in Figure 2, while network size increases from 100 to 1000 nodes under churn of 600 sec, lookup latency of Chord is still kept around 800 ms with failed lookup rate under 10%, and that of Tapestry slightly increases from 900 to more than 1000 ms with failed lookup kept in the range of 10-15%. Kelips showed the worse scalability as its latency increases from 1000 to 1400 ms and failed lookup increases from 40% to over 60% when network grows. This result is highly valuable when choosing a DHT mechanism for large scale mobile P2P applications.

Moreover, increasing churn rate causes higher failed lookup and lookup latency. Another side effect is higher inter-peer traffic to update the topology, which could quickly reduce battery life of mobile devices.

B. Impact of Mobility on Content Distribution Networks (CDN)

A mobile user moving through B3G (Beyond 3G) networks needs to perform vertical handovers. This means the ongoing connection is passed from one wireless access system to another and might also include the passing from one operator to another. A Vertical Hand Over (VHO) between different radio access technologies (e.g. between GSM and WLAN) implies some delay to re-establish the connections. During this period of time Δt_{VHO}, no application data is transferred. Additionally, the switching between radio access technologies results in an abrupt and dramatic change of the mobile peer's uplink and downlink capacity.

Registering to a new access technology might also change the peer's IP address which leads to the loss of all TCP connections currently opened for file transfer. This concerns the peer's ongoing upload and download connections. But even worse, on application layer, when contacting a providing peer with a new IP address, the peer might not keep its old position in the providing peer's waiting queue but re-enters at the end of the queue and waits to be served. In addition, a peer *P* performing a VHO might serve as a providing peer. The IP address change results in lost connections and the peers served by peer *P* need to rediscover *P* by asking the index server for new sources of a file. In standard eMule implementation, this is done periodically every ten minutes. In the following, we will refer to this technique as ***"re-queuing without refill"***.

We proposed an alternative method called ***"re-queuing with refill"***. It introduces a minor modification of the peer's cooperation strategy to improve the system's performance and utilizes the fact that a providing peer knows all peers in its uplink waiting queue before and after the VHO. Thus, the providing peer simply re-identifies itself at the served peers with its new IP address and invites them to continue the download. Thus, it can speed up the recovery after a VHO.

Previously, we assumed that a VHO implies an IP address change. However, approaches like MobileIP preserve the peer's IP address and allow TCP connections to continue after the VHO. These mechanisms lead to an additional delay Δt_{mip}. On application layer, a peer keeps its current connections running which means that it also maintains the position in the uplink waiting queue or is still served. The total transmission delay is $\Delta t_{VHO}+\Delta t_{mip}$

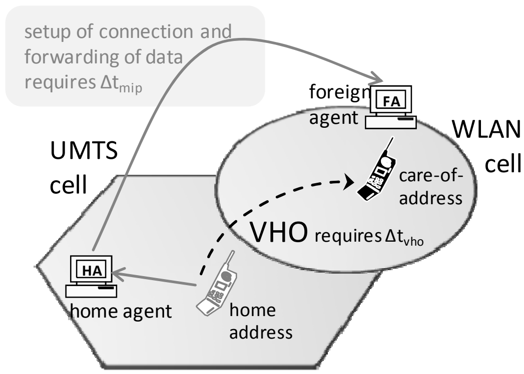

Figure 3. Introduced time delays Δt_{vho} and Δt_{mip} due to vertical handover and mobile IP techniques to overcome re-queuing in P2P system, respectively

We consider a content distribution system based on eDonkey in a heterogeneous wireless environment. The investigated radio access technologies comprise an area-wide UMTS network and WLAN hotspots which may overlap. The considered network layout is based on real antenna locations of a German operator providing both technologies.

As a result of performance studies in [5] , we see that MobileIP techniques are recommended in mobile P2P file sharing systems with respect to download performance, if this technique only requires a small transmission delay below a few seconds. In future network layouts with a better WLAN coverage, the increased uplink capacity will lead to smaller download times. Nevertheless, the performance gain of MobileIP melts in low load situations, since the waiting queues at the providing peers are almost empty and hence the waiting times are almost negligible. In such a scenario, a delay Δt_{mip} exists such that the download performance is even worse than with re-queuing techniques. However, this only happens for unrealistic large delays of tens of seconds.

V. Architecture for Enterprise Mobile P2P Systems & Services

Our previous projects on enterprise applications base on P2P architecture, including: 1) project [5] , in which the Pastry DHT was utilized to store radio measurements and coverage information on the radio access points allowing a seamless vertical handover between WLAN and UMTS and 2) project [10] , in which the Kademlia overlay was used to support network management and networking monitoring.

Base on experiences on mobile P2P applications, we propose an architecture for enterprise mobile P2P system, showed in Figure 4. The Figure illustrates an enterprise network using VPN to connect office branches through the public Internet. From the top-down view, high-level network components form a virtual topology, which hide the details of heterogeneous networking infrastructure. In the case that the P2P network is structured P2P, it may add additional sub-layers below the *virtual topology layer*, which are mechanism-specific overlays, such as a Chord ring.

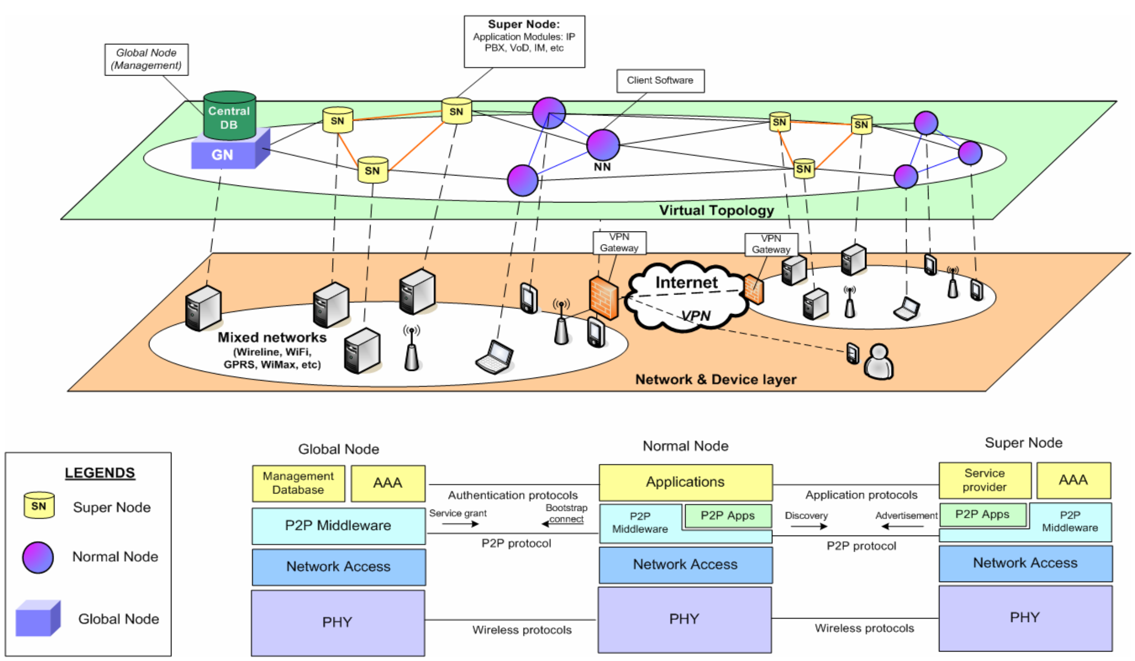

Figure 4: Architecture of enterprise mobile P2P network

Essential components of P2P network include *a)* ***Global Nodes (GN)***, which act as a bootstrap node for other nodes and a service management station base on centralized management database. *b)* ***Super Nodes (SN)***, (e.g. desktop, laptop) which are powerful enough to provide certain resource-demanding services e.g. VoIP, VoD, and *c)* ***Ordinary Nodes (ON) or Normal Node (NN)***, which are mostly mobile nodes with limited resources and capabilities, (e.g. a mobile phone). Regarding the characteristics of mobile P2P network, this architecture mitigate the effect of churn by placing more stable nodes, i.e. super nodes, which help to maintain the overlay when mobile nodes join and leave with high frequency. Moreover, differ from traditional client-server model; this architecture employs an approach of using ticket mechanism for distributed authentication, which is described next.

Upon startup, a normal node should connect to a global node to obtain certain permission and information on the network. After that, it can operate on its own by requesting services from super nodes or exchange data with other Ordinary Nodes. In the protocol stack, P2P middleware plays very important roles of providing lookup, routing and data exchange service by using its P2P mechanisms. Super nodes can use their P2P middleware to advertise their services as well as perform load balancing among them. For user authentication, a special mechanism based on encrypted ticket should be employed in replace of traditional centralized methods. GN and SNs should issue special tickets for ONs on user requests. The ticket contains service grant, user rights and other information so that the ticket owner can request for services from P2P network. For security, tickets should be encrypted using public/private key pair.

Base on this generic architecture, in project [4] a unified messaging system based on P2P architecture was developed to provide VoIP, instant messaging, file sharing, email, fax and video streaming services on both fixed and mobile terminals.

VI. Solutions for Problematic Issues of Enterprise Mobile P2P Network

In order to meet the requirements of enterprise mobile applications, like guaranteed service quality or security, P2P solutions have to introduce some centralized control points for implementing enterprise-specific features. Therefore, hybrid P2P architecture is suggested as a basis for enterprise mobile P2P applications. In general, mobility effects might be leveled by static architecture elements in the mobile operator's domain. For resource access, caches can be used to reduce the load from mobile peers and to increase the availability. For resource mediation, active proxies can be used to locate peers and resources and to pass this information to requesting entities. However, we will see next that sophisticated cooperation strategies can also be used to mitigate the impact of mobility on the performance of resource access control mechanisms. Finally, some solutions for high churn rate of wireless environment are briefly introduced.

A. Performance Improvement of P2P-based Content Distribution

In order to utilize the scarce resources in a heterogeneous network, we develop a simple, but effective algorithm that is trivial to implement in an existing P2P network. The main feature of this algorithm is the iterative adaptation of the number N of parallel uplinks. To ensure the performance improvement by this algorithm, we also introduced an upper bound N_{max} for N, since allowing an unlimited value of N can be negative for the P2P system. This can be explained by the following scenario. A peer in WLAN is able to serve several UMTS downlinks in parallel. A sudden switch to UMTS causes that the downloading peers will be further served with a rather small bandwidth, which is only a 64 kbps / 1,024 kbps = $1/16^{th}$ of the original WLAN uplink capacity in our scenario. Hence, we ensure by setting an appropriate N_{max}, that the minimal bandwidth each connection can be assigned cannot become too small as well as that the time until N has re-adapted to a sensible value keeps short.

The actual implementation of this cooperation strategy initializes each peer with a single uplink, i.e. $N = 1$, whenever joining the P2P network. The peer periodically accumulates the current bandwidths of the active downloading connections. Then, it checks whether the downloading peers have left over some capacity, i.e., the uplink of this peer is not completely utilized. In that case, the number N is increased as long as N_{max} is not exceeded, or until the capacity of the uploading peer is utilized. In contrast, if the result of the capacity check comprises that there is no uplink capacity left, i.e. the downloading peers use the uplink completely, then the number of uplinks is decreased by one. Thus, the remaining N - 1 peers can increase their bandwidth per connection, if they have downlink bandwidth left. Our simulation studies show that this simple mechanism leads to an enormous performance gain compared to common cooperation strategies with a fixed number of upload connections (see Figure 5).

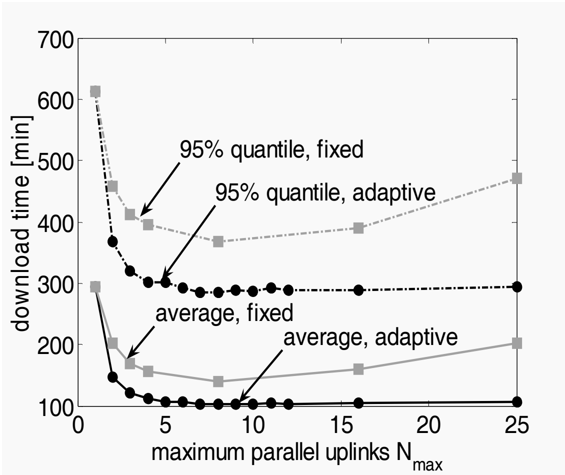

Figure 5. Performance improvement - compared to a common P2P-based CDN - when adapting the number of parallel uplinks to the mobile environment

B. Modified Chord protocol for performance improvement under high churn rate

In an ongoing research, we modify the joining procedure of Chord protocol and its stabilization strategy to improve the consistency of Chord fingers when a new node joins the overlay. By using a locking and signaling mechanism to eliminates concurrent joins, this approach can improve the successful lookup rate under churn. When implemented together with a new flexible proactive ring stabilization mechanism, our modified Chord shows performance gain of up to 100% under high churn rate. The results will be presented in our future papers.

VII. Conclusions and Future Work

This paper presents the issues involved with the development of enterprise mobile network based on P2P architecture. From experiences of previous projects, we proposed a new architecture for typical enterprise mobile P2P system, which is based on hybrid architecture and distributed ticket-based authentication. This architecture is capable of providing various communication services. Regarding designing issues, hybrid P2P based on structured P2P overlay is a very promising candidate for enterprise mobile P2P system.

Major challenges of P2P enterprise mobile network were highlighted and demonstrated by selected experimental results on the impact of mobility in vertical hand-over and high churn rate over DHT performance. Finally, we illustrate several solutions for performance improvement. We propose that P2P systems must perform some cross-layer feedback from lower layer (e.g. MAC & physical layer) to P2P middleware sub-layer in order to adapt P2P control policy to the diversities of heterogeneous networks. In the near future, we will continue to address these issues as well as extend the study to related topics such as energy-efficiency algorithms and security.

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BIOGRAPHY

Nguyen Chan Hung (chanhung@mail.hut.edu.vn) was born in 1973 at Hanoi, Vietnam. He received B. Eng and M.Eng degree in Electronics and Telecommunications at Hanoi University of Technology, in 1995 and 1997, respectively. He obtained his Ph.D. in Telematics from the University of Valladolid, Spain in 2002. He has been working as lecturer and researcher at the Faculty of Electronics and Telecommunications (FET) since 1997, and became Head of Research and Development Laboratory of Multimedia Technology (RDLAB) – FET since 2005. His fields of interest include multimedia networking and applications, P2P overlay network. He has been leading several international collaboration research projects with Panasonic Corp. and Belgium VLIR University association. At present, he is a leader of a national key ICT project titled "Research and Development of Ubiquitous and Mobile Computing Applications", coded name KC.01.10/06-10.

Tobias Hossfeld is a research assistant at the Chair of Distributed Systems, University of Wuerzburg, since 2003. His main research interests cover network virtualization, self-organization mechanisms in overlay networks and P2P systems, with a special focus on mobile environments like 3G and 4G, as well as investigations on quality of experience (QoE). His recent publications cover the application, the modeling, and the performance evaluation of overlay techniques in complex, heterogeneous networks, as well as measurements and traffic characterization of popular Internet applications, like Skype, Joost or YouTube.

Ngo Hoang Giang was born in 1981. He received B. Eng of Computer Science from Hanoi University of Technology in 2004 and M.Eng in 2008 from the same University. At present, he is working as network administrator at Library and Information Network Center, Hanoi University of Technology. His field of Interest includes network monitoring, QoS and performance of P2P network.

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